COPPER IN DECCAN BASALTS (INDIA): REVIEW OF THE ABUNDANCE AND PATTERNS OF DISTRIBUTION

Pramod O. ALEXANDER.& Harel THOMAS

Boletín del Instituto de Fisiografía y Geología

Alexander P.O. & Thomas H., 2011. Copper in Deccan Basalts (India): review of the abundance and patterns of distribution. *Boletín del Instituto de Fisiografía y Geología* **79-81**: 107-112. Rosario, 01-07-2011. ISSN 1666-115X.

Abstract.- In comparison to world larger flood basalts, the Deccan Trap exhibits more than double the amount of copper abundance. This is true for most basalt types but quartz tholeiites are particularly rich in copper, the absolute abundance reaching up to 0.05% Cu in certain areas. In such areas it can be established that apart from entry into silicates and oxides, the major portion of copper was removed as sulphides.

While studying the variation of copper abundance and variation within the Deccan Trap and comparing it with other basaltic rocks around the world, the occurrence of native copper and other cupriferous minerals copper is discussed here. Review of earlier work is done in the light of some new findings. Prospects of finding native copper mineralization and copper rich flows are discussed. It is concluded on the importance of studying the copper mineralization in the Deccan Trap.

Key-words: Deccan Basalts, India, Copper, quartz tholeiites.

Resúmen.- ***Cobre en los Basaltos de Deccan (India): revisión de la abundancia y patrones de distribución.*** En comparación con los mayores mantos volcánicos del mundo, el llamado Deccan Trap muestra una abundancia de Cobre mayor que el doble del promedio. Esto es comprobable para la mayoría de los tipos de basaltos, pero las toleítas cuarcíticas son particularmente ricas en Cobre, alcanzando hasta un 0.05% en determinadas áreas. En dichas áreas pudo establecerse que además del ingreso en silicatos y óxidos, la mayor parte del Cobre fué removido como sulfuros.

Sobre la base del estudio de la variación de abundancia de Cobre en el Deccan Trap, incluyendo una comparación con otras rocas basálticas de distintas partes de la Tierra, se discute la ocurrencia de Cobre nativo y otros minerales cupríferos. Una revisión de trabajos anteriores se lleva a cabo a la luz de nuevos hallazgos. Estrategias y métodos para el hallazgo de Cobre nativo y coladas ricas en Cobre son discutidas. Se concluye sobre la importancia de estudiar las mineralizaciones de Cobre en el Deccan Trap.

Palabras clave: Basaltos de Deccan, India, Cobre, Toleítas cuarcíferas.

Adresses of the authors:

P.O. Alexander: *Department of Applied Geology - School of Engineering and Technology, Dr. H. S. G. Central University, Sagar, India.*

H. Thomas [harelthomas@yahoo.com]: *Department of Applied Geology - School of Engineering and Technology, Dr. H. S. G. Central University, Sagar, India.*

Received: 21/02/2011; accepted: 10/06/2011

INTRODUCTION

Copper is one of the ubiquitous trace elements in basaltic magma. During magmatic crystallization its complex geochemical behaviour can make it appear either in silicates and oxides, sulphides or in native state. About 60-70% of the world copper production comes from sulphides of the late magmatic, hydrothermal stage. However, the Upper Michigan basalt flows hosting an outstanding deposit of native copper is a reminder that where massive basaltic lavas occur, chances of finding deposits of native copper cannot be ruled out.

In spite of being one of the largest basaltic provinces in the world, the minor and trace element distribution in the the extensive basaltic plateau of the Deccan Trap (Fig. 1) has received attention only in the last years. The present paper presents a review of the occurrence of native copper and sulphides in the Deccan Trap considering our new observations and, then, a brief discussion on the abundance and distribution patterns of Cu in Deccan basaltic rocks. Cu concentration in the north-east corner of the Deccan province showing the highest value (up to 0.05% Cu), is considered in some detail.

COPPER IN DECCAN BASALT

The interest of one of the authors (POA) in the subject began in the decade 1970 when studying a large part of the Deccan Trap and carried out an intensive geochemical research of the northeastern corner of the Deccan province (Alexander 1977, Alexander & Paul 1977). Exceptionally high values for copper (around 500 ppm by XRF and confirmed by Emission Spectrograph) in these parts together with stray occurrences of native copper, sulphides and malachite prompted a more detailed regional study on the subject.

Only recently high quality data for Cu abundance in the western side of Deccan Trap are available. Main data are compiled in Table 1, pending a statistical analysis.

NATIVE AND COPPER MINERALS IN DECCAN TRAP

Deccan Trap covers extensive areas in the states of

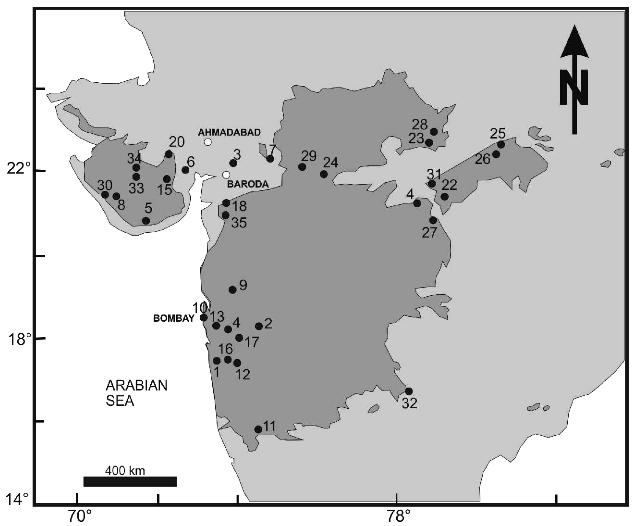

Figure 1. The Deccan Outcrop showing localities for the occurrences of native copper and other copper minerals. See Table 1 for locality names.

Table 1. Compilation of mean contents of Cu (in ppm) in the Deccan volcanics. Main localities located in Figure 1.

Locality	Cu	Reference
Western parts		
01. Ambenali	210	Cox & Hawkwesworth (1985)
02. Bhimashankar	212	Cox & Hawkwesworth (1985)
03. Botad	102	Krishnamurthy (1974)
04. Bushe	103	Beane et al. (1986)
05 Dedan	069	Krishnamurthy (1974)
05. Dhandhuka	105	Krishnamurthy (1974)
07. Dohad	259	Alexander (1977)
08. Girnar	139	Murali (1974)
09. Igatpuri	137	Alexander (1977)
10. Khandala	169	Beane et al. (1986)
11. Koyna	309	Alexander (1977)
12. Mahabaleshwar	217	Beane et al. (1986); Nefaji et al. (1981)
13. Neral	104 238	Cox & Hawkwesw. (1985), Beane et al. (1986)
14. Nipani	100	Ghose & Trofimov (1972)
15 Pavagrah	094	Alexander (1977)
16. Poladpur	183	Beane et al. (1986), Cox & Hawkwesw. (1985)
17. Pune	296	Alexander (1977)
18. Rajpipla	130	Krishnamurthy (1974)
19. Thakurvadi	131	Beane et al. (1986)
20. Wadhwan	102	Krishnamurthy (1974)
21. Bhoiwada	351	Vallance (1974)
Central and Eastern Part		
22. Chhindwara	230	Alexander (1977)
23. Dewalchori	517	Alexander (1977)
24. Indore	100	Ghose & Trofimov (1974)
25 Jabalpur	215 163	Alexander (1977), Ghose & Trofimov (1972)
26. Katangi	205	Alexander (1977)
27. Nagpur	155	Ghose & Trofimov (1972)
28. Sagar	321	Alexander (1977)
29. Malwa Traps, Dhar		
Poladpur Formation	175	Khadari et al. (1999)
Bhimashankar Formation	248	Khadari et al. (1999)
Deccan Trap Dykes		
28. Sardhar dyke, Saurashtra	132	Alexander (1977)
29. Pachmari dyke, Central India	289	Alexander (1977)
30. Hyderabad	158	Alexander (1977)
31. Jetpur, Gujrat	100	Alexander (1977)
32. Rajkot, Gujrat	122	Alexander (1977)
33. Nandurbar, Maharashtra	225	Melluso et al. (1999)

Maharashtra, Gujarat and Madhya Pradesh. Engineering constructions and excavations have been helpful in presenting better rock exposures and their structures, and thereby exposing copper mineralization in the past. More than twenty localities in these three states are known to have provided records of occurrences of native copper and sulphides/oxides of copper. One of the better known locality is the Mojdam site in the Saurashtra region, about 3 km southeast Bhayavadar (21°51'N, 70°15'E) described by Roy (1969). Other localities in Gujarat include Beh (22°17'N, 69° 30'E), Sherdi (21°35'N, 70°08'E), Buri (21°33'N, 70°07'E) and Athmanbara in Jamnagar district; Jetpur (21°43'N, 70°07'E), Virpur (21°51'N, 70°42'E) in Rajkot district and Gir Forest (21°03'N, 70°54'E) in Junagarh district. From Maharashtra, where the Deccan Trap has maximum coverage, native copper has been recorded from

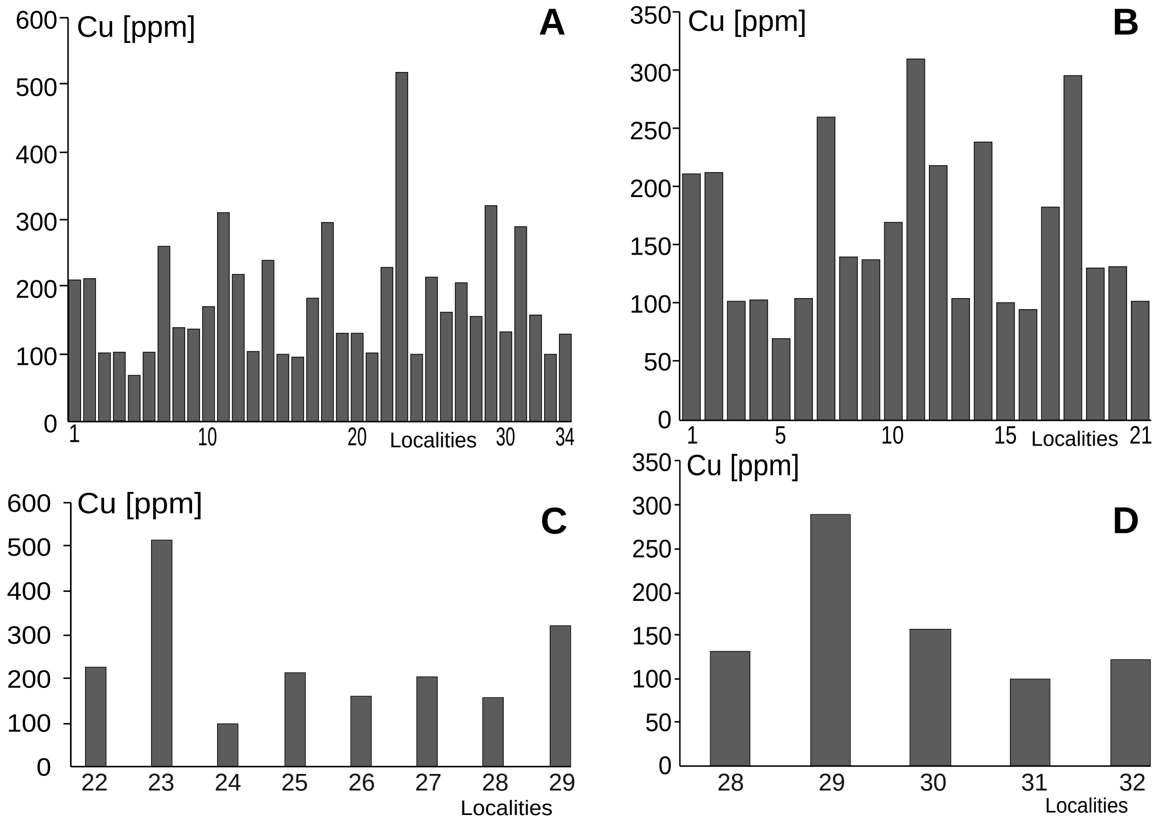

Figure 2. Distribution of Cu abundance in the Deccan Traps. Numbering of localities as in Table 1 and partially in Fig. 1. **A.** Distribution in the Deccan volcanics in the whole area. **B.** Distribution in localites of the western part. **C.** Distribution in localities of central and eastern parts. **D.** Distribution in the Deccan trap dykes.

Kohlapur (16°42'N, 74°55'E), Sirsondi (20°26'N, 74°25'E) and at Jalakundi (17°24'N, 73°45'E) in a quarry excavated for the Koyna Project. Native copper has also been reported from Handigund (16°25'N, 75°05'E) in the Belgaum district of Karnataka near the Maharashtra border. Most of these occurrences among others appear to be too small and limited and have been described briefly by Raghunandan et al. (1981) and also earlier by Dunn & Jhingran (1965) and Radhakrishna & Pandit (1973). In the north-eastern part of the Deccan, specks of native copper and chalcopyrite have been observed in Sagar district (23°56'N, 78°38'E) by one of the authors (POA). Malachite stains have also been noted generally in the topmost flows of the Sagar, Narsinghpur, Jabalpur and Chhindwara districts of Central India. Figure 1 gives an overall picture of occurrence of native copper and other copper minerals in the Deccan Basalts.

DISCUSSION

Copper concentration in “basalts” has an arithmetic mean value of 116 ppm and a median of 100 ppm (Prinz, 1967). Earlier reported values are even lower: Vinogradov (1962) indicates 100 ppm, Wedepohl (1962) 88 ppm, Turekian & Wedepohl (1961) 87 ppm. Deccan Trap basalts, which on the average have quartz tholeiitic composition exhibit more than normal abundance of copper. In this study, around 200 high quality determinations are considered with an attempt to study its geographical and petrological variations within the Deccan Trap and comparing it with other flood basalts.

The abundance of Cu for different localities in western and central regions of the Deccan Basalts is compiled in Table 1. From the large number of data which are not included in Table 1, it is observed that the lowest value is 45 ppm for basalt from

Table 2. Arithmetic mean (*m*) and median (*M*) of Cu abundance in different basalt types. Values in ppm.

		Quartz normative tholeiite	Olivine normative tholeiite	Olivine normative alkali basalt	Nepheline normative basalt
Deccan Trap	*m*	299	97	120	122
	M	307	106	101	120
World Average (Prinz 1967)	*m*	135	75	126	47
	M	125	75	105	35

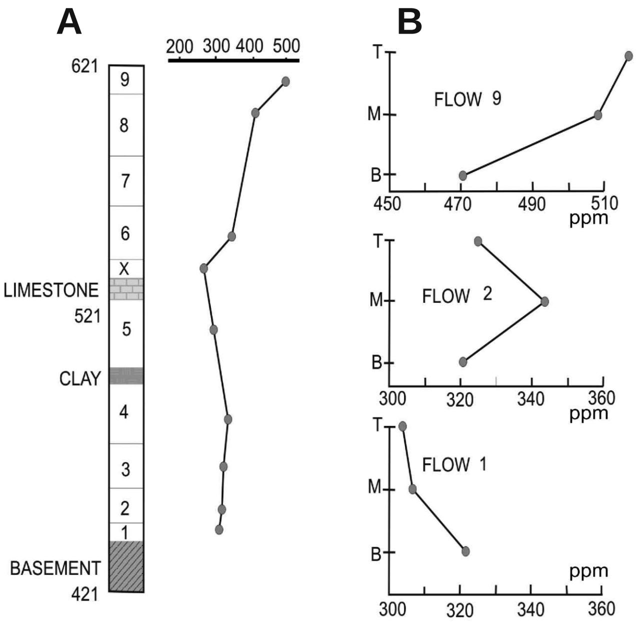

Figure 3. A. Variation of Cu contents (in ppm) in the ten-flow sequence at Sagar, showing a consistent trend of maximum values towards the top of the sequence. **B.** Intra-flow variation of Cu contents (in ppm) in the flows 1, 2 and 9 showing different trends through the basal (B), middle (M) and upper (T) portions of each flow.

Girnar, Western India (Murali 1974) while the highest, 540 ppm, is for basalt from Dewalchori (23°45'N, 78°34'E) in the Sagar district (Alexander 1977) and both being quartz tholeiites in character. Fig. 2 shows copper abundance in the Deccan Trap as a whole, irrespective of rock type showing a consistent pattern: within the wide variation in absolute values, ranging from 45 to 540 ppm of Cu, values higher than 200 ppm are generally restricted to quartz normative tholeiites.

Out of the available data for the Deccan Trap, the normative character for 129 basalts is known. In Table 2 it is used to characterize the variation in copper abundance in term of different basalts types, and, at the same time, compared with the world average for the same type. Considering the arithmetic mean among the Deccan Trap, the highest Cu concentration is found in the quartz normative tholeiites (299 ppm) like in the case of basalts around the world. But the difference is larger than twice, the Deccan quartz tholeiites being richer in copper. In the world average, next in the order of decreasing abundance are olivine normative tholeiites (126 ppm) and the nepheline normative basalt poorest, with 47 ppm Cu only. However, surprisingly, in case of the Deccan Trap, nepheline normative basalt is next to quartz tholeiite in their copper abundance (122 ppm) which is nearly three times the world average for the same type (47 ppm).

After comparing other flood basalts of the world, and some of the well known basaltic units, the Deccan Trap shows invariably greater abundance of copper. Indeed, the value of 299 ppm of the Deccan Trap is much higher than those of 148 ppm of Columbia river basalt (Prinz 1967), 125 ppm of Koweonuan lavas of Michigan (Prinz 1967), 197 ppm of the Shaergaard intrusion, 126 ppm of Aleutian volcanism, Alaska (Prinz 1967), 125 ppm Karroo basalt (Alexander 1977). 110 ppm of Siberian Trap (Nesterenko et al. 1967). The Kilauea basalts of Hawaii (207 ppm Cu, Prinz 1967) having more than normal copper abundance than in average basalts, fall poorer to Deccan basalt from this point of view.

Table 3. Ratios Cu/Na and Cu/Fe of the five flows of the higher part of the sequence.

Flow	Cu / Na	Cu / Fe
9	0.027	0.0059
8	0.021	0.0052
7 (weathered)	0.016	0.0041
6	0.020	0.0051
5	0.017	0.0040

There are some smaller volcanic piles which apparently have greater copper abundance than the Deccan. Seachondong basalt flow in Yongyang basin Korea contains on the average 1020 ppm Cu (Lee and Kim, 1970). Similarly, Triassic volcanics of North Mountain, Nova Scotia, Eastern North America have recorded Cu abundance which is higher than for the Deccan Trap. Sinha (1970) has established that the average value in the North Mountain basalt is 496 ppm Cu, which is comparable to the higher copper values of the Deccan Trap around Sagar (see Alexander 1977) but portions of Nova Scotia have even 683 ppm Cu which is quite remarkable.

Within the Deccan Trap itself, there seems to be considerable variation in Cu abundance from different localities (Table 1) in the north eastern corner around the Sagar District, exhibiting the highest abundance with an average of 321 ppm. The highest flow around Dewalchoril (23°45'N, 78°34'E) having the highest value of 540 ppm copper. In other parts of Deccan, especially the western Ghats, values of over 200 ppm Cu are fairly common in individual flows like at Khandala (366 ppm), Koyana (309 ppm), Ambenali (299 ppm), Pune (296 ppm), Mahabaleshwar (290 ppm), Poladpur (268 ppm). Dohad, an isolated outcrop near Pawagarh, has also a fairly high Cu content of 259 ppm (Alexander 1977, Cox & Hawkesworth 1985, Beane et al. 1986). Even within a small area within the same petrographic type, however, there can be considerable variation in copper concentration of basalt. Two quartz tholeiites from Girnar show values of 45 and 279 ppm respectively (Murali 1974). Similarly, there is a considerable variation in flows of the Neral Formation. Commonly, Mg-rich flows have an average content of Cu of 104 ppm, while giant phenocryst basalt in the same locality in Western Ghats have on the average, 238 ppm Cu (Beane et al. 1986). This would suggest that the large phenocrysts of plagioclase are the main host for Cu in these flows.

In restricted areas of the Deccan where acid differentiates accompany basalts, as around Bombay, the Cu values drop down to 12 ppm in trachytes and rhyolites (Lightfoot et al. 1984) while Deccan trap dykes of different ages are comparable to average Deccan Trap in their Cu contents, ranging from 100 ppm to 289 ppm (Table 1).

Copper in Sagar Flows

Abundance of Cu in the 190 m thickness basaltic plateau at Sagar (23°56'N, 78°38'E) has been studied in greater detail (Alexander, 1976). General concentration of copper in this singular quartz tholeiite province is far richer with an average of 341 ppm as against 100 ppm for the average basaltic rocks. Among the ten-flow sequence, the flow 5 is the oldest (Alexander & Paul, 1977) and the mean content is 293 ppm Cu. Inter-flow variation for the entire sequence is represented in Fig. 3A. Five flows of the higher sequence exhibit a normal differentiation trend (Alexander 1988), increasing from lower to higher flows with a maximum of 500 ppm in the topmost flow.

Taylor (1965) has pointed out that Cu^{++} is closer in ionic size to Fe^{++} among the major elements and Cu is geochemically similar to Na^{+}. The Cu-O bond is more covalent than either the Na-O or Fe-O bonds, as is clearly shown by both electro negativity and ionization potential values (I Cu^{+}/I Na^{+} = 1.53 and I Cu^{++}/I Fe^{++} = 1.25). Thus Cu/Fe and Cu/Na ratios should increase during fractionation. The four non weathered flows of the higher part of the sequence which have a normal differentiation trend have the ratios indicated in Table 3. This table does not[?] show the entry of part of Cu into silicate lattices substituting for Na^{+} and Fe^{++} and possibly Ca in plagioclases and pyroxenes. Since titanomagnetite is a significant phase in these high titania basalts (average TiO_2, 2.55%) a portion of copper is bound to be with that phase as has also been demonstrated by Vincent in this study of copper contents of Skaergaard minerals (Vincent 1974). In view of considerable high copper concentration of these basalts it is however, reasonable to assume that the bulk of Cu must have separated originally as immiscible sulphides. This is supported by the presence of native copper and copper sulphides in these basalts as also by the presence of secondary copper minerals like malachite stains in particular.

Intra-flow variation in copper is also considerable and pattern varied. In Fig. 3B three different patterns are shown. In flow 9, the trend is what is generally known to be true with maximum Cu concentration towards the top of the flow (517 ppm) with 407 ppm at the bottom and 508 ppm in the middle portions. Flow 2 exhibits another trend where maximum Cu concentration is observed in the middle portion of the flow. Flow 1 shows a pattern which is exactly reverse of flow 9 with maximum Cu concentration in the bottom layers (321 ppm) while Cu concentration decreasing progressively upwards. This however, is not surprising as the entire geochemical trends in the flows of the lower sequence in this area are demonstrated to exhibit a reserved trend (Alexander 1988)

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CONCLUSION

There are over 30 areas of basaltic lavas around the world that are known to contain Cu, some of which with potential commercial value (Cornwall 1956). The present paper aims to bring together two different, yet related aspects of the Deccan Trap (one of the world largest continental volcanic piles). Occurrence of native copper in them, and their absolute abundance. It is worth to ask if the latter could serve as a guide to the former. Obviously, with the enormous size of the Deccan outcrop, the present field and analytical data are not enough to make categorical statement but certain observations and suggestions for further studies in the field arise.

1. The Deccan Trap exhibit significantly higher copper values than the average basaltic rocks including the major flood basalt provinces of the world. This fact indicates an anomalous source region with respect to this metal. Even from the Proterozoic to Mesozoic Zanskar sequence of Kashmir it has been reported the occurrence of native copper that is apparently related to trap rocks of the Phe volcanics (Lydekker 1823, Raghu-Nandan et al. 1981). “Zanskar” in Ladakhi language means “Copper Fort”. Some of the Cu nodules recovered from this area in ancient times are up to 10 kg weight (Lydekker 1823, Wadia 1978). Therefore, it should not be surprising to find within the massive Deccan volcanic pile the existence of other areas of native Cu and sulphides mineralization together with Cu rich flows (like that of Seachondong basalt in Korea, see Lee & Kim 1970) which could consist of smaller deposits.

2. Most of the discoveries of native copper and sulphides occurrences from the Deccan Trap came to light during engineering excavations for railways, roads and at dam sites. In our opinion Cu occurrence in other localities is very probable. Exploration might be focussed on vesicular, scoracious, pipes, fractured and brecciated portions of the trap, as also ash beds. Malachite stains (which can be confused with the common secondary mineraloid “green earth”), which can be easily tested in the field with rubeanic acid paper, has been helpful in the authors experience to locate sulphide minerals and high copper proportions within a basaltic plateau. Basalt with exceptionally high Cu concentration are significant as such but may or may not indicate native copper mineralization within a flow or nearby. In Lake Superior region, the Keweenwan lavas which host the richest deposit in the world of native copper have almost normal abundance (125 ppm, Prinz 1967).

3. Subvolcanic intrusions within the Deccan Trap also need to be examined specifically with this purpose. It can be recalled here that copper occurs in sulphides ores associated with the subvolcanic intrusions of the Siberian Trap (Nalvikin 1960).

4. Even though there is potential for finding many new localities for copper mineralization in the Deccan Trap, it is unlikely that these have a scale as that of the Lake Superior Copper deposit. Obviously, there are differences in the tectonic environment, the latter constituting a volcanogenic-sedimentary sequence in a geosynclinal setup while the Deccan is a typical continental flood eruptions. However, several small occurrences of native copper and sulphides and flows that are abnormally rich in copper brought together can be a substantial future potential for this strategic metal once the enormous area and volume of volcanic pile is considered. It is significant to note that in Sagar flows which have the highest recorded Cu abundance in the Deccan Trap, over 300 ppm of Copper of flow 9 (which contains on the average 500 ppm of Cu) is removed easily by treatment with cold, weak acids. Sodium Acetate-Acetic acid mixture is also capable of extracting the bulk of copper from powdered basalts. This form of Copper, readily extractable from an ordinary rock material, should be attractive for when regular supply of this important base metal reaches exhaustion. Moreover, it could be tried bacterial leaching on high copper basalts. Bacterially extracted copper from low grade ores and mine wastes is a practice that is increasingly becoming adopted in USA, Canada and Australia.

Acknowledgements.- We are thankful to Prof. Arun K. Shandilaya, Department of Applied Geology (University of Sagar, India) for its support. Two anonymous referees have greatly contributed for enhancing the manuscript.

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